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KIRBY MORGAN DIVE HELMET 37 EVALUATION (UNMANNED)

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19. ABSTRACT:
The Kirby Morgan Dive Helmet 37 (KM 37) underwater breathing apparatus (UBA) was evaluated for freezing water resistive effort (RE) using air (from 0 to 198 feet of seawater [fsw]) and an 88/12 helium-oxygen mixture (from 165 to 380 fsw) as the breathing media, in salt water maintained at 29 ± 1 °F (−1.7 ± 0.6 °C); freezing water operations; and carbon dioxide (CO_2) retention (ventilation sufficiency). The KM 37 met the NEDU RE goal of 1.76 kPa at an RMV of 62.5 L/min to 132 fsw with air and to 380 fsw with HeO_2. From the results of unmanned testing for RE, CO_2 retention and freezing-water performance, operation is very similar in performance to the ANU-approved and Fleet-fielded MK 21 MOD 1.

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INTRODUCTION

Navy Experimental Diving Unit (NEDU) was tasked to test and evaluate commercially available diving equipment to determine its suitability for Navy use.[1] Accordingly, NEDU performed a quick-look evaluation of the Kirby Morgan 37 helmet (KM 37) to determine whether this helmet was safe for manned evaluation in the NEDU test pool and Ocean Simulation Facility (OSF). Results of the NEDU quick-look evaluation (unmanned) have been detailed in a technical letter.[2] Naval Sea Systems Command (NAVSEA) then tasked NEDU to further evaluate the KM 37 helmet for possible inclusion among equipment listed as Authorized for Navy Use (ANU).[3] An NEDU test plan was created to prescribe the additional unmanned tests as part of this further evaluation, including a freezing water resistive effort (RE) evaluation, a freezing water dive profile, and carbon dioxide (CO_2) retention (ventilation sufficiency) assessments.[4]

Evaluations were performed on five KM 37 helmets (serial numbers 4088KM, 4117KM, 4119KM, 4120KM, and 4121KM) in NEDU's Experimental Diving Facility (EDF) Bravo hyperbaric chamber. The helmets were configured with the Tri-Valve™ double-exhaust valve system and quad-cover during all evaluations. The KM 37 helmet uses the SuperFlow™ 350 regulator. All evaluations were performed with the helmet in the vertical orientation, simulating a diver standing upright. A schematic showing the test setup follows the listing of references for this report.

METHODS

Resistive Effort Method. RE evaluations were performed with both air and mixed gas (88/12 HeO_2) breathing media in the Bravo chamber. Those using air as the breathing medium were performed with a single 300-foot length 3/8-inch inside diameter (ID) umbilical. A single 600-foot length of 3/8-inch ID umbilical was used during mixed-gas RE evaluations. The umbilicals and helmets were submerged in an ark, a large water bath in Bravo chamber, in salt water maintained at 29 ± 1 °F (–1.7 ± 0.6 °C). Umbilicals were supplied from a volume tank having an approximate internal volume of 2.3 ft^3 (65 L).

The required minimum manifold (MM) gas supply pressures — measured at the volume tank in psig — were determined in accordance with the following formula:

$$MM = (\text{depth} \times 0.445) + \text{recommended supply pressure for depth}, \qquad \textit{(Equation 1)}$$

where depth is in feet of seawater (fsw).

For the U.S. Navy (USN) MK 21 helmet, the minimum recommended supply pressure in psig for depth is shown in Table 1.[5] Testing of the KM 37 helmets used the minimum pressures required for the MK 21.

Table 1.
Recommended supply pressures for depth

Depth (fsw)	Pressure (psig)
0–60	90
61–130	135
131–190	165

For mixed-gas evaluations, 165 psig was used as the recommended supply pressure for depth value in *Equation 1.*

Manifold pressures were set at each depth, with the steady-flow and emergency gas supply valves closed and the breathing simulator off. After establishing the correct MM pressure for depth on the breathing gas supply console of Bravo chamber, the helmet regulator adjustment (dial-a-breath [DAB]) knob was adjusted by remote control at each depth before simulated breathing and data collection were begun. If the helmet was free flowing, the DAB was adjusted until bubbles exhausting from the demand regulator reached a minimal trickle or stopped. If the helmet was not free flowing, the DAB was adjusted until exhaust bubbles appeared and was then readjusted as described. After the DAB adjustment was completed, the breathing simulator was started, and data collection was begun.

RE evaluation for five KM 37 helmets was performed with air as the breathing medium from 0 to 198 fsw (60.7 meters of seawater [msw]) in increments of 33 fsw (10.1 msw; 1 atmosphere absolute [ATA]). RE was evaluated with HeO_2 as the breathing medium from depths of 165 fsw (50.5 msw) to 363 fsw (111.2 msw) in 33 fsw increments and at 380 fsw (116.4 msw). RE was evaluated at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min respiratory minute volumes (RMVs). Breathing simulator settings were in accordance with Table 2.

Table 2.
Breathing simulator standard settings

Frequency (Breaths per minute)	V_T (Liters)	RMV (L/min)	Diver Work Rate
15	1.5	22.5	Light
20	2.0	40.0	Moderately Heavy
25	2.5	62.5	Heavy
30	2.5	75.0	Severe
30	3.0	90.0	Extreme

At each depth and RMV combination, 10 pressure-volume (P-V) loops were recorded. The RE, a volume-averaged pressure, was reported in kPa for each ensemble average of the 10 P-V loops generated at each depth and RMV.

The RE performance goal for Category 2 umbilical-supplied demand UBAs is 1.76 kPa for RMVs up to 62.5 L/min.[6] At RMVs greater than 62.5 L/min, NEDU Technical Manual 01-94 provides no established RE goal for Category 2 UBAs.

A three-step process was used to determine whether the RE met the Category 2 UBA performance goal of 1.76 kPa:

Step 1: Was the RE ≤ 1.76 kPa? If yes, the goal was met. If not, proceed to Step 2.

Step 2: Was the RE statistically > the goal when a one-tailed, one-sample t-test was applied? If yes, the goal was not met. If not, proceed to Step 3.

Step 3: Was the RE standard deviation (SD) value acceptable? If yes, the goal was met. If not, the goal was not met.

Technical Manual 01-94 does not specify a maximum allowable SD for RE values for Category 2 UBAs. It does, however, specify an allowable SD (0.2 kPa) for RE values for Category 1 demand UBAs with the RE goal of 1.37 kPa.[6] However, we believe it is reasonable to multiply the specified Category 1 SD goal by the ratio of the Category 1 and Category 2 RE goals to approximate an acceptable SD for Category 2 UBAs:

$$\text{Category 2 SD goal} \approx (\text{Category 2 RE goal} / \text{Category 1 RE goal}) \times 0.2 \qquad \textit{(Equation 2)}$$

$$\text{Category 2 SD goal} \approx (1.76 / 1.37) \times 0.2$$

$$\text{Category 2 SD goal} \approx 0.26 \text{ kPa}$$

Freeze-up Evaluation Method. Using air as the breathing medium, a freeze-up evaluation was performed with five KM 37 helmets. Each helmet was dived to a depth of 198 fsw (60.7 msw) with the breathing simulator set to 62.5 L/min and in salt water maintained at 29 ±1°F (–1.7 ±0.6°C). The salt concentration in the salt water was maintained at approximately 34‰ (parts per thousand). The freeze-up dive profile is shown in Figure 1.

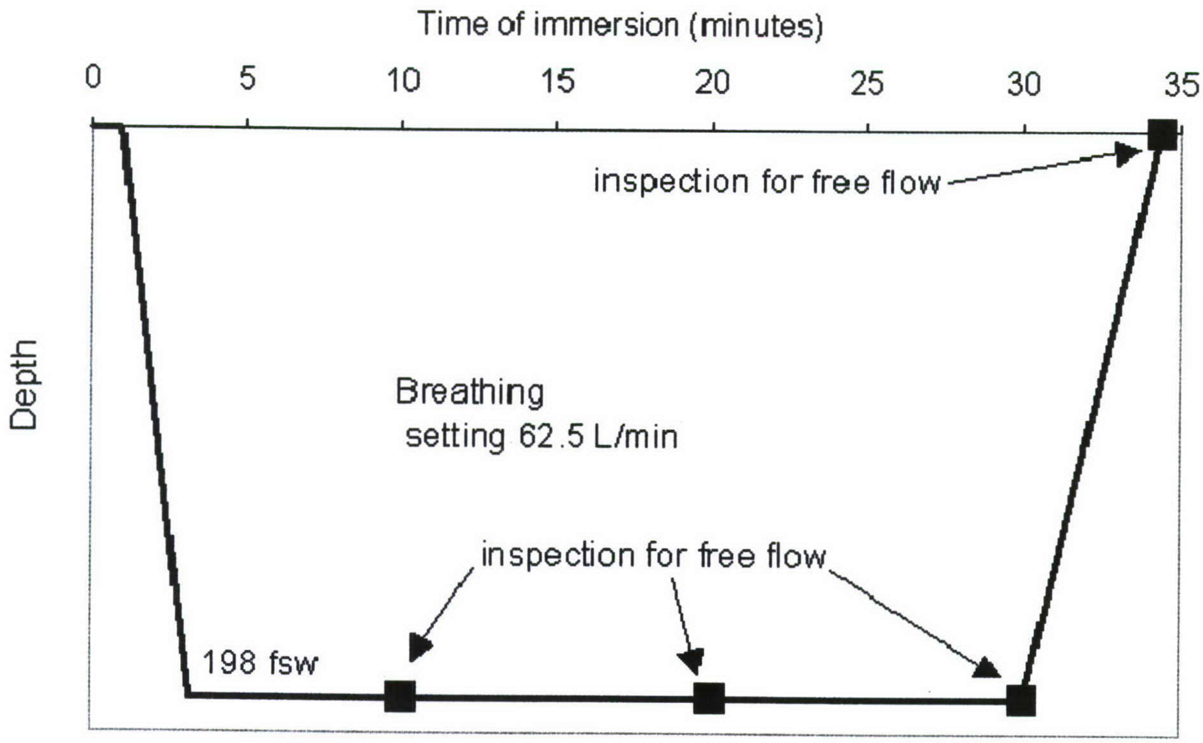

Figure 1. Dive profile used for the freeze-up tests.

Carbon Dioxide Ventilation Sufficiency Method.

With the helmet positioned on a human mannequin head and immersed in a water tank inside the Bravo hyperbaric chamber, testing was conducted at two water temperatures: 28° and 80 °F (about –2° and 27 °C). The combinations of depths and breathing gases included air at 50 and 198 fsw (about 15 and 60 msw) and HeO_2 (88/12) at 165 and 380 fsw (about 50 and 115 msw). A breathing simulator (Reimers Consulting; Springfield, VA) was used to generate a minute ventilation of either 22.5 or 62.5 L/min. Carbon dioxide was injected at a rate of 4% of the minute ventilation. Gas continuously drawn from the mannequin's mouth was analyzed for CO_2 with a fast-responding infrared absorption analyzer (Model CD-3A with a P-61B sensor, Applied Electrochemistry Ametek; Pittsburgh, PA). The sampling frequency of the breathing simulator's volume and of the CO_2 readings was 100 Hz.

Warkander and Lundgren's method[7] was used to calculate dead space. The amount of inspired CO_2 (ACO_2) was determined with *Equation 3* (illustrated in Figure 2):

$$ACO_2 = \Sigma\, PCO_2 \cdot \Delta V, \qquad (Equation\ 3)$$

where PCO_2 is the CO_2 concentration at the mouth. The dead space (V_d) was calculated as

$$V_d = ACO_2 / P_{ET}CO_2, \quad (\textit{Equation 4})$$

where $P_{ET}CO_2$ is the CO_2 level at the end of the expiration (end-tidal CO_2). The average inspired CO_2 ($P_{in}CO_2$) can be calculated for any end-tidal CO_2 as

$$P_{in}CO_2 = P_{ET}CO_2 \cdot V_D / V_T, \quad (\textit{Equation 5})$$

where V_T is tidal volume.

The delay time between the CO_2 and volume signals was determined after all data were collected through the following method: the difference between the amount of CO_2 exhaled and the amount reinhaled had to be the amount of CO_2 injected. The dead space volume was determined from data collected during about 75 seconds at each minute ventilation and depth.

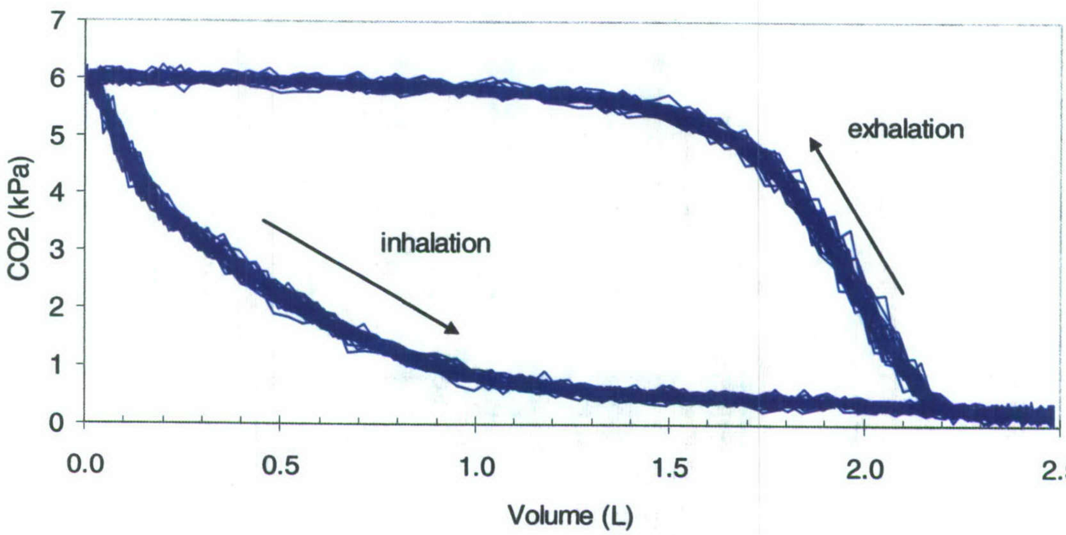

Figure 2. Plot of how the CO_2 level varied with tidal volume. Data from 32 breaths from one KM 37 helmet are shown. Test conditions included a minute ventilation of 62.5 L/min at 198 fsw (60 msw) with the helmet immersed in water at 80 °F. Every inhalation started at the upper left part of the figure and ended at the lower right. The area under the inhalation curve represents the volume of inhaled CO_2.

RESULTS

Resistive Effort Results. Results of RE data analysis for the KM 37 evaluation of freezing water RE are summarized in Tables 3 and 4 and in Figures 2 and 3.

Table 3.
KM 37 RE results with air as the breathing medium. Values shown are in kPa. Water temperature was 29 ± 1 °F (−1.7 ± 0.6 °C).

RMV (L/min)	0 fsw	33 fsw	66 fsw	99 fsw	132 fsw	165 fsw	198 fsw
22.5	0.85	0.90	1.08	1.12	1.13	1.16	1.21
40.0	1.03	1.16	1.35	1.40	1.37	1.46	1.56
62.5	1.19	1.42	1.66	1.68	1.67	1.93 (B)	2.36 (B), (C)
75.0	1.26	1.55	1.84 (A)	2.02 (B)	2.00 (B)	2.68 (B), (C)	(XP)
90.0	1.35	1.81 (A)	2.15 (B), (C)	3.05 (B), (C)	3.21 (B), (C)	(XP)	(XP)

(A) The actual RE value > 1.76 kPa; however, the t-test indicates that the value is not statistically > 1.76 kPa. Therefore, the RE goal is met.
(B) The actual value > 1.76 kPa, and the t-test indicates that the value is statistically > 1.76 kPa. Therefore, the RE goal is not met.
(C) The SD > 0.26 kPa; therefore, the RE goal is not met.
(XP) The measured peak pressure > the test termination criterion of 7 kPa.

Table 4.
KM 37 RE results with HeO_2 (88/12 mixture) as the breathing medium. Values shown are in kPa. Water temperature was 29 ± 1 °F (−1.7 ± 0.6 °C).

RMV (L/min)	165 fsw	198 fsw	231 fsw	264 fsw	297 fsw	330 fsw	363 fsw	380 fsw
22.5	0.97	0.98	0.99	1.03	1.06	1.08	1.07	1.08
40.0	1.22	1.23	1.28	1.32	1.37	1.38	1.39	1.41
62.5	1.44	1.48	1.57	1.62	1.71	1.75	1.80 (A)	1.84 (A)
75.0	1.54	1.59	1.68	1.80 (A)	1.93 (C)	2.00 (B)	2.08 (B), (C)	2.18 (B), (C)
90.0	1.69	1.77 (A)	1.89 (A)	2.04 (A)	2.33 (B), (C)	2.85 (B), (C)	3.29 (B), (C)	(XP)

(A) The actual RE value > 1.76 kPa; however, the t-test indicates that the value is not statistically > 1.76 kPa. Therefore, the RE goal is met.
(B) The actual value > 1.76 kPa, and the t-test indicates that the value is statistically > 1.76 kPa. Therefore, the RE goal is not met.
(C) The SD > 0.26 kPa; therefore, the RE goal is not met.
(XP) The measured peak pressure > the test termination criterion of 7 kPa.

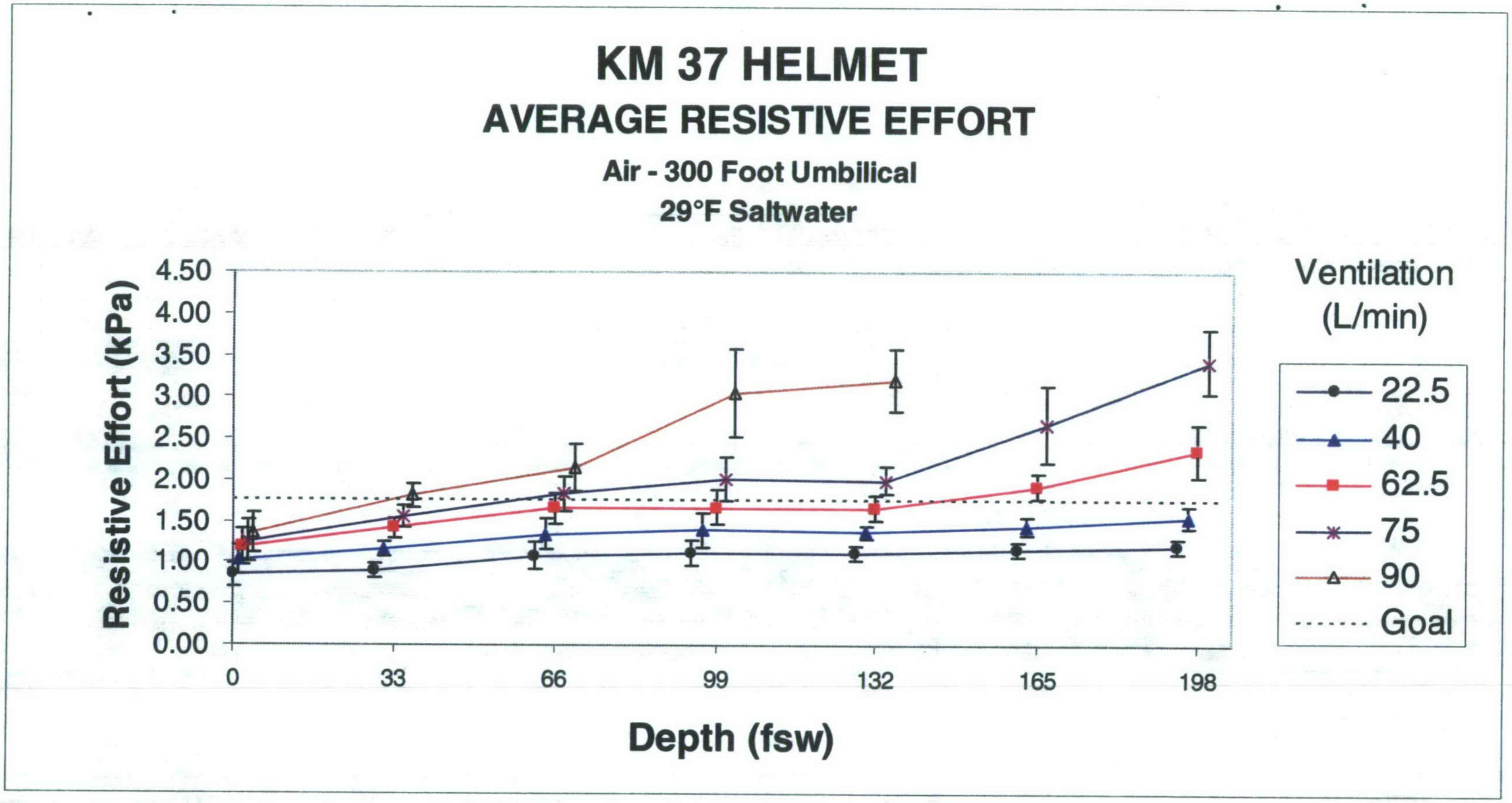

Figure 3. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures, no data point is shown for 90 L/min at 165 and 198 fsw. ("Excessive pressures" means that the measured peak pressures exceed the testing termination criterion of 7 kPa.) All data points represent five samples.

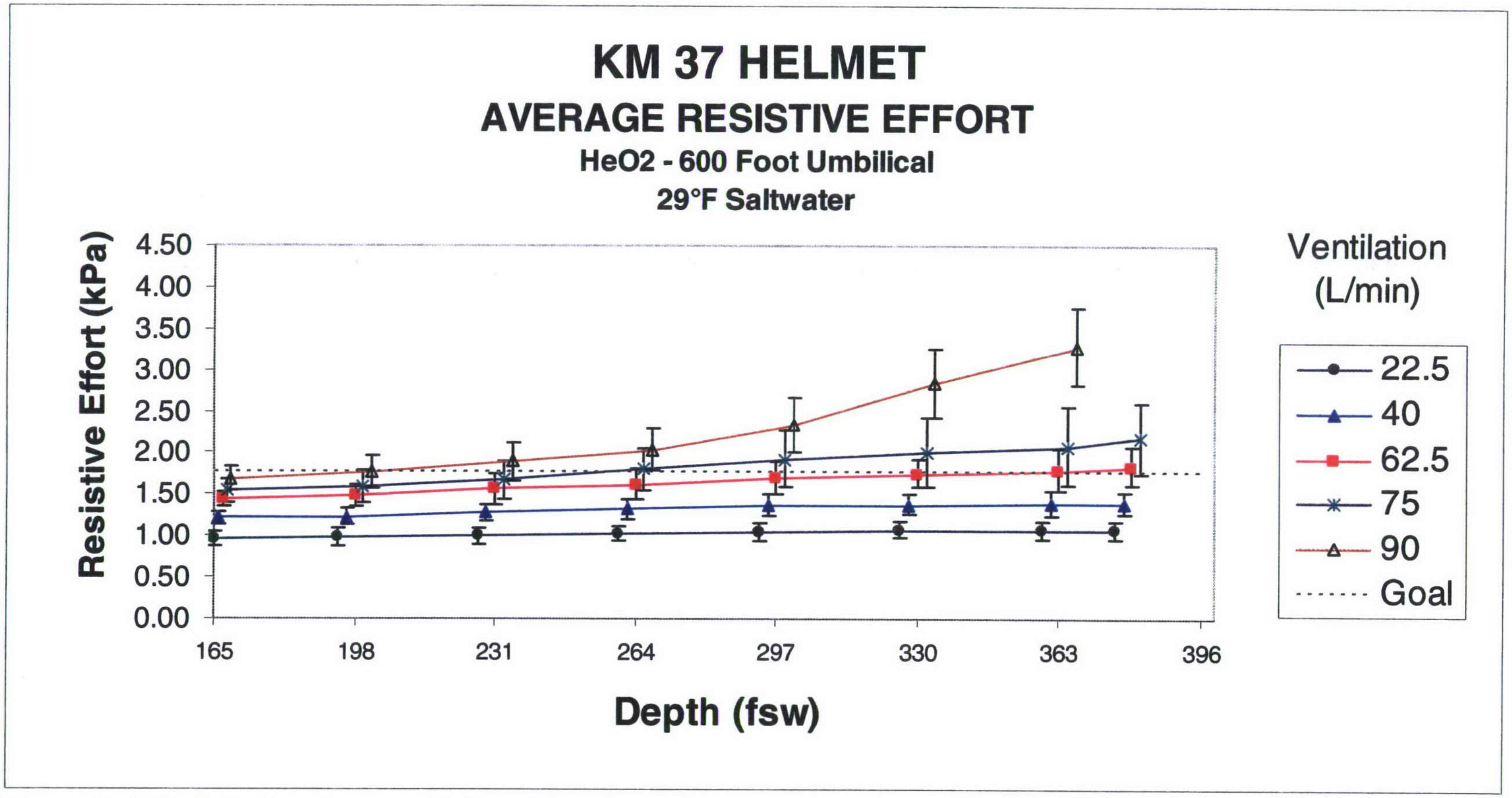

Figure 4. RE plotted against ventilation. Error bars show standard deviation. To improve readability, the symbols are slightly offset horizontally. The dashed line shows the RE performance goal (1.76 kPa) for Category 2 UBAs. Because of excessive pressures, no data point is shown for 90 L/min at 380 fsw. ("Excessive pressures" means that the measured peak pressures exceed the testing termination criterion of 7 kPa.) The data point for 90 L/min at 363 fsw represents four samples; all other data points represent five samples.

Freeze-up Evaluation Results. No indications of freeze-up were observed during the five KM 37 freeze-up evaluation dives.

CO_2 Ventilation Sufficiency Results. The overall dead space for the four helmets for which a complete data set was obtained averaged 0.28 L. It did not change appreciably with depth (for either gas) or with water temperature. However, the minute ventilation significantly influenced the size of the dead space: on the average, it decreased 0.05 L ($p<0.002$) at a breathing rate of 62.5 L/min (mean, 0.25 L) compared to one of 22.5 L/min (mean, 0.30 L).

For a diver who maintains the typical sea level end-tidal CO_2 level of 5.3 kPa (40 mm Hg), the volume-averaged inspired CO_2 would be 1.48 kPa (% surface equivalent value [SEV]) by *Equation 3*. If the diver instead maintains the more common end-tidal CO_2 level of 6.0 kPa (45 mm Hg), the volume-averaged inspired CO_2 would be 1.68 kPa (% SEV).

The average dead space in the mask was 0.28 L, but it varied with the minute ventilation. Apparently the seal around the face improved with the elevated minute ventilation. Therefore, less CO_2 from the helmet was reinhaled.

Warkander and Lundgren[7] have shown that the minute ventilation increases by about 57% per liter of dead space. Therefore, a dead space of 0.28 L would force an increase of about 16% in the diver's minute ventilation.

In comparison, Warkander and Lundgren have determined the dead space of the Interspiro Divator MK II full face mask (MK 20) to be 0.20 L.[7] However, the larger dead space of the KM 37 — which is comparable to the MK 21 dead space — should not cause any concern. Previous tests have shown that there is no statistically significant difference between the KM 37 and MK 21 helmets in terms of CO_2 ventilation sufficiency.[2] Table 5 presents helmet dead space data.

Table 5.
Dead space (in liters) in the KM 37 at each combination of breathing gas, depth, minute ventilation, and water temperature (average of measurements on four helmets).

Gas	Air				HeO_2			
Depths	50 fsw (15 msw)		198 fsw (60 msw)		165 fsw (50 msw)		380 fsw (115 msw)	
Minute ventilation (L/min)	22.5	62.5	22.5	62.5	22.5	62.5	22.5	62.5
29 °F	0.31	0.23	0.32	0.32	0.28	0.21	0.27	0.20
80 °F	0.32	0.26	0.34	0.31	0.29	0.22	0.28	0.25

CONCLUSIONS

Resistive Effort. The KM 37 helmet met the RE performance goal (1.76 kPa) for Category 2 UBAs during simulated air dives from 0 to 198 fsw in 29 °F salt water at RMVs of 22.5 and 40.0 L/min. At an RMV of 62.5 L/min, the RE goal was met from 0 to 132 fsw. At an RMV of 75 L/min, the RE performance goal was met from 0 to 66 fsw. At an RMV of 90 L/min, this goal was met to 33 fsw.

During HeO_2 (88/12) dives in 29 °F salt water, the KM 37 helmet met the 1.76 kPa RE goal to a depth of 380 fsw — the maximum depth tested — at RMVs of 22.5, 40.0, and 62.5 L/min. For RMVs of 75.0 and 90.0 L/min, the RE performance goal was met to 264 fsw.

It should be noted that RE values are affected by the setting of the regulator adjustment knob. Although the regulator adjustment knob was set according to a defined procedure, this procedure did not define a unique, singularly acceptable knob position for each test scenario. Due to the inherent subjectivity of the regulator adjustment, some variability in RE values could be expected if tests were repeated.

Based upon the most recent unmanned RE data available for the MK 21 (sample size n=3 and with air as the breathing medium) the RE performances for the KM 37 and MK 21 appear to be similar.

Freeze-up Evaluation. No contraindications to diving in 29 °F salt water were found during the freeze-up evaluation dives with the KM 37 helmet.

Carbon Dioxide Ventilation Sufficiency. The dead space in the KM 37 helmet was 0.28 L, which would be expected to cause an increase in the minute ventilation by about 16%, a fairly common value. The oro-nasal cup inside the KM 37 helmet sealed well against the mannequin used in these tests. The difference between CO_2 ventilation sufficiency for the KM 37 and MK 21 helmets is not significant.

Summary. From the results of unmanned testing for RE, CO_2 retention, and freezing-water performance, operation is very similar to the ANU-approved and Fleet-fielded MK 21 MOD 1.

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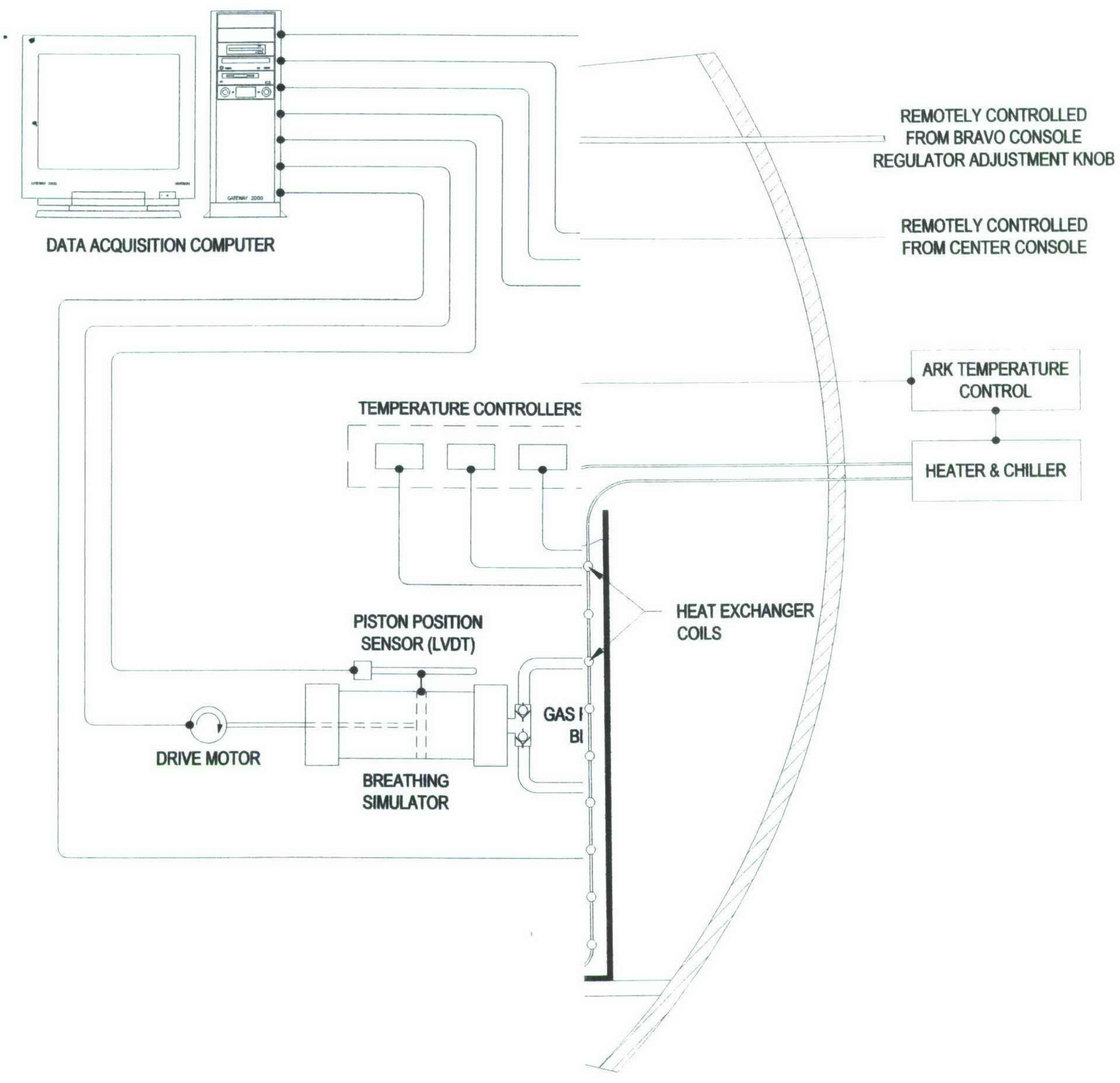
NOTE:

1. HELMET MOUNTED ON MANNEQUIN HEAD (NOT SH
2. ORAL PRESSURE REFERENCE AT MANNEQUIN SUI



— LEGEND —

- ONE-WAY CHECK VALVE
- ELECTRICAL CONNECTOR
- 1 1/4 IN. I.D. FLEX TUBING

U.S. NAVY EXPERIMENTAL DIVING UNIT

PANAMA CITY, FLORIDA 32407

KIRBY MORGAN HELMET (KM 37)
TEST SETUP DIAGRAM

NUMBER: NAVSEA TA 06-09 / NEDU TP 06-36

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